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# EUROPEAN PATENT APPLICATION

21 Application number: 89201370.7

51 Int. Cl.<sup>4</sup>: G02F 1/00 , G02F 1/01

22 Date of filing: 29.05.89

A request for correction of page 17 - line 34, page 22 - line 23, page 29 - lines 25 - 32 has been filed pursuant to Rule 88 EPC. A decision on the request will be taken during the proceedings before the Examining Division (Guidelines for Examination in the EPO, A-V, 2.2).

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30 Priority: 30.05.88 NL 8801377

43 Date of publication of application:  
 06.12.89 Bulletin 89/49

84 Designated Contracting States:  
 AT BE CH DE ES FR GB GR IT LI LU NL SE

54 Electro-optical component and method for making the same.

57 Electro-optical components and semi-manufactured articles, and method for making them. A light conducting layer is formed from a poleable or poled glassy polymer material, which has an under ionizing radiation definitively destructible e/o activity. A selective irradiation under a parallel beam will give sharp transitions (C, D) from an e/o active area (2. 1) or an area which can still be activated to an e/o non-active area. The buffer layers (3 and 5) can also consist of suchlike irradiated material.

A suitable positioning of the electrodes (4 and 11) between which by means of a difference in voltage applied across the connections (12 and 13) an electric field with a sufficient intensity and/or uniformity can be induced extending into the border area, on both sides of the transition planes (C, D), will make sharp inducible refractive index transitions possible. This is utilized with e/o inducible waveguides in thin layers to obtain sharp lateral definitions, and in an optical intermediate switch.

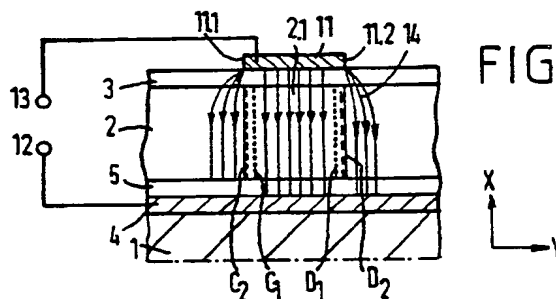


FIG. 4

EP 0 344 857 A1

## Electro-optical component and method for making the same.

### A. Background of the invention

#### 1. Field of the invention

The present invention relates to the conduction of light in thin layers, and more in particular to components with suchlike layers comprising a medium with electro-optical (e/o) properties with which under the influence of an electric field changes in the refractive index are induced in the medium in such a way that as a consequence of that the conduction of light in the thin layers will be influenced.

Moreover the present invention comprises a method for making components of the above-mentioned type.

The invention is especially applied in the field of integrated optical techniques.

#### 2. State of the art

Components of the aforesaid type are known per se, for example from the references (1), (2), (3) and (4) mentioned under D. They comprise a substantially plane light conducting layer of e/o active material, and are moreover provided with at least two co-operating electrodes disposed on one side or on both sides on said layer in patterns preselected, and possibly kept separated from the e/o active layer by light insulating or buffer material - which is not e/o active and with a refractive index which is equal to or lower than the e/o active material in a non-activated state. Owing to a difference in voltage applied an electric field will be generated between said electrodes, which field will, as long as it exists, cause in the e/o material a spatial refractive index profile or a change in it dependent on the direction and the extent of uniformity of the electric field induced between these electrodes, and on the direction of the optical axis of the material. Because of the fact that the working of the electric field induces in the e/o material a spatial refractive index profile, said profile will be strongly dependent on the electrode patterns chosen. Known are straight or bent usually strip-shaped electrodes, of which at least two of them either parallel next to each other, as in (2), or one over the other, as in (1) work together, i.e. across which the required difference in voltage for the desired electric field is applied in the desired direction. Moreover it is known from reference (1) and reference (3) that the strip-shaped electrodes on

the one (upper) side of the plane layer of e/o material work together with an electrode extending over the whole plane layer on the other (under) side of said layer.

The spatial refractive index profiles induced by means of electrode patterns of the aforesaid type are usable as light waveguides in the plane light conducting layer, to which a connection of permanent light waveguides such as for example glass fibres is feasible. As to their nature these e/o inducible light waveguides can be switched on and off. The refractive index profiles for the desired light waveguide patterns obtained by the electrode patterns known from the cited literature have a somewhat tube-shaped character with often more or less elliptical cross sections. A cross-sectional view shows that a change in the refractive index is greatest in the centre area and away from it decreasing, either gradually to the level of the refractive index of the e/o material, on which the inducing electric field has no or hardly any influence as yet, or at a leap to the level of the refractive index of the contiguous non-e/o buffer material.

The light retaining quality of the induced light conductor, particularly with regard to losses of light energy is dependent on the quality of the lateral definition, with which is indicated the degree of steepness of the decrease, or the leap in the course of the refractive index towards the level of the refractive index of the surrounding material seen in cross section from the centre area of the light conductor. The lateral definition is determined either by the electric field itself or by the bounding surfaces of the e/o material contiguous to the non-e/o material. With regard to this definition the bounding surfaces at the top and at the bottom will usually not cause any difficulties, certainly not in the case of thin layers with thicknesses to 10  $\mu\text{m}$ . The electric fields obtained by means of co-operating electrode patterns on both sides of a plane layer of e/o material of a thickness of said order of magnitude are immediately on both sides of said bounding surfaces such that a sufficiently great refractive index leap will be induced. The lateral definition on both sides of the induced light waveguide in the plane layer itself will, however, be determined exclusively by the course of the electric field strength and its decreasing uniformity. In that case the decrease of the strength of the field away from the centre area of the light conductor will always have a certain graduality and this does not make it possible to achieve a sharp refractive index transition. A better lateral bounding can be obtained by laterally bounding the e/o material with light insulating material. This is aimed at in the

above-cited technique, such as disclosed in references (2) and (3), by placing an extra elongated ridge of e/o material integrated with the plane layer underneath it, in which case, however, part of the bounding is still determined exclusively by the electric course of the field. Besides suchlike lateral boundings of the e/o material are obtained by means of otherwise known photolithographic techniques, in which case the e/o material is applied as a layer after which that part of the material which is not usable for the light conductor(s) is etched away. Apart from the fact that this involves extra complicating processes, the side planes obtained by said etching away still keep a great extent of wall roughness with regard to the conduction of light.

As a solution to said problem, which is even greater in the outside curve of a bend of a ridge-shaped light conductor, reference (4) proposes to cover suchlike ridge-shaped light conductors with a special upper layer of heat resistant synthetic resin of an accurately determined thickness, with which the optical losses in consequence of wall roughness will be reduced. Apart from the fact that it remains to be seen whether due to the above solution in most cases a sufficient reduction of said losses can be achieved, it will remain laborious to utilize that solution.

Reference (1) further discloses an e/o component in which a light waveguide can be induced as it were between two more or less reflecting vertical parallel "walls" at a short distance from each other in the thin layer of e/o material. These reflecting "walls" can be induced by electric fields generated between two pairs of strip-shaped co-operating electrodes disposed on both sides of the e/o material, which fields can effect a decrease of the refractive index in the e/o material between each of the pairs of electrodes. The e/o area between the "walls" will not or hardly be influenced by the fields, and has then to serve as a light waveguide. The lateral definition of such a waveguide will here be more or less complementary to the one of the above-described cases and consequently even less good from a qualitative point of view.

From reference (3) it is further known that the e/o material in the area where two electrodes disposed on both sides of the plane layer work together is locally poled. This means that the e/o material in that area got its optical orientation when the component was made. This takes place by bringing the poleable glassy polymer, of which the e/o material consists, under the influence of an external electric field, when it is still in a state above the glass softening temperature. The electric field may be generated via said co-operating electrodes. Said optical orientation has subsequently been frozen as it were by cooling it down. Outside

said area the material is isotropic and non-e/o active, but here too the lateral definition of the light waveguide induced in that area cannot be better than the one determined by either the course of the instantaneous inducing electric field or by the course of the degree of ("frozen") e/o activity in consequence of the field under the inducing influence of which the material is poled; all this depends on the degree to which the instantaneous field corresponds to the field with which has been poled.

Summarizing it can be stated that in this known technique in the field of the e/o influencing of the conduction of light in thin layers e/o induced refractive index transitions, especially those which serve for a total reflection, as used in the case of the temporary establishment of light waveguides, the lateral definition is substantially determined either by the inducing field or by bounding surfaces contiguous to non-e/o buffer material, which bounding surfaces, obtained e. g. by means of known lithographic techniques, have a relatively great wall roughness. This can in both cases lead to unwanted losses of light energy in the e/o components, in the second case the making of them is moreover extra complicated.

#### B. Summary of the invention

The object of the present invention is to provide not only e/o components for the conduction of light in thin layers in which for the purpose of influencing the conduction of light e/o inducible refractive index transitions have been defined more sharply than it would have been possible when applying the known technique, but also a method for making suchlike components. A further object of the present invention is to provide an improvement of the lateral definition of light waveguides e/o inducible in thin layers.

The invention is an application of the discovery that the irradiation of a poleable (e/o still neutral) or poled (e/o active) polymer material, of a sort as known per se from the references D (3) and D (6), by an ionizing radiation will definitively annul the e/o activity, which can be activated or is activated by poling, in which case sharp shadows will be obtained by a selective irradiation with a parallel bundle under covering by means of for example a mask, that means sharp transitions from an e/o active area or an area which can still be activated to a non-e/o active area in originally the same material. This offers the possibility of defining, especially in components in which suchlike e/o material is used in thin layers for the conduction of the lightwave in such layers, sharper e/o inducible refractive index transitions than known hitherto.

For that purpose an e/o component, which comprises

- a mainly plane light conducting layer comprising a certain e/o active area, and

- at least two at least partly co-operating electrodes disposed against said layer in preselected patterns, between which electrodes an electric field with a working extending into the e/o active area can be generated by applying a difference in voltage between said electrodes,

is according to the invention characterized in that the light conducting layer consists of material with an under ionizing radiation destructible e/o activity, in which the e/o active area is left open beforehand by means of selective irradiation, and in that the electrodes have been positioned with regard to the area left open in such a way that a difference in voltage applied across the electrodes induces such a field distribution that at least in a border area on either side of the place where the area left open borders on irradiated material the electric field will show a high degree of intensity and/or uniformity. This means that in said border area a refractive index profile with a sharp leap can be defined by arranging an inducing electric field of a sufficient intensity and/or uniformity at the place where an e/o active area changes over to an irradiated, so e/o non-active area. Said leap is caused because of the fact that due to the inducing field the refractive index in the e/o active area on the one side of the change-over undergoes a change, whereas on the other hand the refractive index in the e/o non-active area on the other side of the change-over does not undergo a change.

Because of the fact that irradiated material no longer shows e/o activity, such material can be used as light insulating buffer material between non-irradiated e/o active material and electrode material of electrodes directed at the e/o active material. For that purpose buffer material, which may be provided for keeping the electrodes separated from the e/o active area, preferably belongs to the irradiated part of the plane light conducting layer.

When using the invention for improving the lateral definition of a light waveguide of a sort described in reference D (2) which is e/o inducible in a thin layer, an e/o component according to the invention will preferably be such that the electrodes are situated on one side, called the upper side, of the layer, and that the e/o active area left open includes an e/o inducible light waveguide pattern, the e/o active area on the upper side seen in a perpendicular projection on the layer being flanked by a corresponding pattern of co-operating strip-shaped electrodes.

When using the invention for improving the lateral definition of light waveguides which are e/o inducible in a thin layer, as they are known from

reference D (3), an e/o component according to the invention is preferably such that the electrodes are situated on both sides on the upper side and on the under side of the light conducting layer, and that the e/o active area left open includes an e/o inducible light waveguide pattern, the e/o active area on the upper side seen in a perpendicular projection on the layer being covered by a corresponding pattern of strip-shaped electrodes.

For making e/o components according to the invention it may be preferable that the e/o active area left open in the layer has, lateral with regard to that layer, substantially vertical bounding surfaces with the irradiated area, and that seen from the upper side in a perpendicular projection on the layer the contours of the electrodes situated on the upper side of the layer and of the e/o active area left open at least partly coincide. The advantage of this is that in the case of a selective irradiation by means of masks the same or complementary masks can be used for selectively irradiating and for applying electrode patterns. If an electrode pattern in itself has been sharply defined, such a pattern itself can also serve as a mask for selective irradiation. Such a freedom of choice of masks enhances the flexibility during the making process of said e/o components.

Sharp e/o inducible refractive index transitions are very suited for switching purposes, in which case use is made of the direction influencing effect that refraction or reflection at such transitions has on light signals incident at a certain angle. For that purpose the light conducting layer in a preferred embodiment according to the invention comprises at least one permanent light waveguide connected to the e/o area left open in said border area.

From reference D (5) it is known per se to connect for switching purposes permanent light waveguides, provided by local poling in a neutral poleable light conducting polymer layer, to a working area in which a (totally) reflecting refractive index transition can be induced and removed again. This inducing and removing takes, however, place by unpoling the working area or by poling it again, in which case a local heating up to above the polymer softening temperature is effected for a short time while setting up the poling field or not. Such an excitation of the refractive index transition is based on a molecular reorientation (Kerr effect) and can consequently be effected much more slowly than the one based on e/o activity exclusively due to electron response (Pockels effect). Moreover, in this case too the sharpness of the refractive index transition is fully determined by the course of the field with which the working area has been poled. As an optical switch an e/o component according to the present invention is preferably such that the light conducting layer includes at

least three permanent light waveguides, which are connected to the e/o active area left open in said border area, and that the connection of each of the light waveguides to this area takes place at such an angle that for a light signal incident through one of the permanent light waveguides a totally reflecting refractive index transition can be induced, and that when there is a refractive index transition inducing field or not, one of the other permanent light waveguides will receive and further conduct the light signal.

The concept "selective irradiation" also includes the process of subjecting the polymer material to two or more interfering radiation beams, which cause an interference pattern in the material. This can be of advantage for bringing about periodical structures in the polymer material, such as for the sake of e/o inducible bars.

The invention further relates to a method for making e/o components as described hereinabove for introducing an e/o active area into a plane light conducting thin layer, characterized in that this introducing takes place by leaving open the e/o active area in the plane light conducting layer by means of selective ionizing irradiation, in which case preferably use is made of U.V.light.

Moreover, it can be preferable that the e/o active area left open in the plane light conducting layer is obtained by selective ionizing irradiation by means of a mask which is also used for the electrode pattern to be disposed.

To conclude the invention relates to a semi-manufactured article which can be used with advantage for making the above-described e/o components according to the invention. Such a semi-manufactured article comprises a mainly plane light conducting layer, which is supported on the under side by a substrate and which is provided on the upper side with a light insulating first buffer layer. Such a semi-manufactured article is according to the invention characterized in that the light conducting layer consists of a material with an under ionizing radiation destructible e/o activity, which layer has a first sublayer of said material non-irradiated, and a second sublayer of said material irradiated and forming the first buffer layer.

A semi-manufactured article of the aforesaid type can moreover also comprise a second light insulating buffer layer, which is separated from the light conducting layer by an electrode layer disposed between the light conducting layer and the substrate, the second buffer layer preferably also consisting of the irradiated form of said material. Such semi-manufactured articles have the great advantage that for making e/o components according to the invention by utilizing the method according to the invention the necessary processes can always be carried out from above.

#### Summary of the advantages:

The invention offers the possibility to give the e/o area in plane layers any desired pattern with a sharp lateral definition, on which the lateral spread of an E-field inducing in it will have no influence. The electrode width will no longer be critical for the lateral definition.

The manufacturing process for establishing e/o areas in thin layers is considerably simplified.

Even light insulating buffer layers can be disposed in a simple way.

#### C. Brief description of the drawing

The invention will be further explained with the aid of the drawing, in which

Figure 1 diagrammatically shows a cross-sectional view of semi-manufactured articles for making e/o components according to the invention, (a) excluding, (b) including an electrode layer,

Figure 2 diagrammatically shows a cross-sectional view in an X-Y plane the structure of two variants (a) and (b) known per se of components with e/o inducible light wave-guides in which the invention has been applied,

Figure 3 shows the qualitative course of the refractive index profile in two directions represented in Fig. 2 by the e/o active area of the component (a) in case  $X = \text{constant}$ , (b) in case  $Y = \text{constant}$ ,

Figure 4 diagrammatically shows in a cross-sectional view in the X-Y plane the structure of a component known per se with an e/o inducible light waveguide in which the invention has been applied,

Figure 5 shows the qualitative course of the refractive index profile in two directions represented in Fig. 4 by the e/o active area of the component (a) in case  $X = \text{constant}$ , (b) in case  $Y = \text{constant}$ ,

Figure 6 diagrammatically shows a top view (Y-Z plane) of an optical intermediate switch according to the invention,

Figure 7 diagrammatically shows in a cross-sectional view (X-Y plane) the optical intermediate switch according to Fig. 6 (a) according to the line VII a, (b) according to the line VII b.

#### D. References

(1) US Patent No. 3695745 entitled: Light waveguide circuit;

(2) US Patent No. 3 801 185 entitled: Switch for thin-film optics;

(3) EP Patent application No. 0241967 A1 entitled:

Electro-optically induced waveguide, and active devices comprising such a waveguide;

(4) EP Patent application No. 0149678 A1 entitled:

Integrated optical circuit;

(5) NL Patent application No. 8702804 of applicant entitled:

Method and device for controlling a beam of light (not yet published);

(6) NL Patent application No. 8700787 entitled:

Linear addition polymer with hyperpolarizable side groups (not yet published).

### E. Description

In the following description of some embodiments to illustrate the invention it is supposed that an organic polymer of a sort as already known from inter alia references D(3) and D(6) is used as a material for a plane thin light conducting layer. Such a polymer has a skeleton ("backbone") of for example PMMA or polyurethane with e/o sidegroups, which possess dipole moments which can be directed or are "poleable" by means of an external electric field when the polymer is still in its softening state, i.e. at a temperature still above the glass softening temperature. Under cooling down and maintaining the field this "poling" is retained, so frozen as it were and gives the material an optical orientation. As a consequence the material is at the same time brought from an unidirectional optically isotropic (i.e. neutral) state into a state in which the material is e/o active. Such a layer of poleable polymer material can be poled for example in its entirety with an E-field directed perpendicularly to the thin layer, which field is generated between plane electrodes on either side of the thin layer, which has a difference in voltage (pole voltage) across it, which is just below the breakdown voltage of the polymer material. A local poling is also possible with an E-field (not necessarily orthogonally directed at the thin layer) generated between co-operating electrodes with suitably chosen patterns on one side or on both sides of the thin layer. The e/o active area thus obtained in the thin layer can, in view of the high e/o coefficient of suchlike material (see reference D (3)), work under a relatively low voltage (even to a factor of 10 lower than the poling voltage) between the electrodes for generating the E-field. As it is known a change in the index of refraction  $\Delta n > 0,005$  at  $1 \text{ V}/\mu\text{m}$  is possible, so that operating voltages of 5-10 v can be used when the thicknesses of the layer are for example of the order of

magnitude of 1-10  $\mu\text{m}$ . The changes in the index of refraction can be positive as well as negative. In the case of operating voltages with a sign corresponding to the poling voltage it applies that  $\Delta n > 0$  and in the case of operating voltages with an opposite sign it applies that  $\Delta n < 0$ . Now it has appeared by experiment that the irradiation of such a polymer with e/o side groups by ionizing radiation such as for example U.V.light definitively destroys these side groups and consequently the e/o effect. This destruction occurs with poled material as well as with unpoled material, which means that poling and selectively irradiating are interchangeable processes. Moreover a small change in (decrease of) the index of refraction occurs with regard to the one of the material in the neutral state, or in a state in which the material has not been e/o activated by an instantaneously existing electric field. A polymer with a polyurethane skeleton irradiated by U.V.light (by means of a "mask-aligner" KS-MJB 3 HP, 200 W high pressure Hg-lamp) showed:

- a change in the refractive index in the order of magnitude  $\Delta n = 0.1$ ;
- a penetrating speed of the destructing effect in a plane layer of  
ca.  $1 \mu\text{m}/\text{h}$ . at  $130^\circ \text{C}$ , and of  
ca.  $1/2 \mu\text{m}/\text{h}$ . at  $20^\circ \text{C}$ , both with a transition zone of about  $1 \mu\text{m}$ ;
- the occurrence of very sharp shadows, with a resolution of 0.1-0.2  $\mu\text{m}$  with layer thicknesses to 10  $\mu\text{m}$ , under selective irradiation by means of masks;
- that the polymer remains transparent also for the U.V.light used.

The invention contains the application of light conducting polymer material with the aforesaid kind of effects under ionizing irradiation, viz.

- (i) destruction of the e/o activity, and
- (ii) sharp cast shadows,

for obtaining sharp e/o inducible refractive index transitions for the purpose of influencing the conduction of light in thin mainly plane layers of suchlike material. All this can be realized by combining a selective irradiation of the e/o material with a suitable choice and position of the means for generating the inducing electric field, in such a way that at least in a border area on both sides of the boundary line between e/o active and e/o non-active material, which boundary line is obtained due to said selective irradiation, the electric field can show a high degree of uniformity and/or intensity. In this case material inactivated by irradiation can also serve as light insulating buffer material between electrode material and e/o active material.

Hereinafter follows the description of three examples in which the invention has been applied, to wit in two of them for the purpose of the lateral

definition of e/o inducible light waveguides in thin layers, and in one of them for the purpose of an e/o inducible light reflector also in a thin layer. Preceding this description follows hereinafter a brief description, with the help of Figure 1, of the structure of a semi-manufactured article from which and with which e/o components according to the invention can be made, and in which semi-manufactured article the invention can already have been applied.

Figure 1 (a) shows a semi-manufactured article consisting of a substrate 1 of for example glass or an Si-wafer with an SiO<sub>2</sub> upper layer, with on this substrate 1 a light conducting layer 2 of organic poleable or poled glassy polymer of which the e/o activity can be destructed under ionizing irradiation, such as U.V. light. The light conducting layer 2 may be provided with a first buffer layer 3 which is transparent for the ionizing irradiation, and which can consist of a layer of for example SiO<sub>2</sub> or polystyrene separately applied to said buffer layer, or, as according to the invention, obtained from the irradiation of a light conducting layer of said polymer by U.V. light of a well defined depth of penetration, which light conducting layer originally comprised the layers 2 and 3 of the figure. The advantage of said buffer layer is that for making the semi-manufactured article one step less in the procedure of applying the layers is required. It is generally simpler to carry out irradiation than to apply an extra layer.

Figure 1 (b) represents a semi-manufactured article comprising not only a substrate, a light conducting layer 2 and possibly a first buffer layer 3, as in Figure 1 (a), but moreover a first electrode 4 of for example aluminium or gold, which can be extended immediately on and over the whole surface of the substrate 1, and a second buffer layer 5, which keeps the first electrode 4 separated from the light conducting layer 2. Also the second buffer layer 5 can, just like the first buffer layer 3, consist of either buffer material which differs from the material of the light conducting layer 2 or of irradiated glassy polymer. In the latter case this layer 5 has been applied during the manufacturing process for example in a separate step and subsequently entirely been irradiated before the light conducting layer, possibly including the layer 3, can follow. Another possibility is to obtain the second buffer layer 5 by irradiation of the light conducting layer 2 from the underside, if both the substrate 1 and the first electrode 4 have been made of a material which is transparent for ionizing radiation.

Semi-manufactured articles according to Figure 1 are pre-eminently suited for making e/o components according to the invention. The great advantage is that all the processes needed for that purpose can take place from above and on top of the

semi-manufactured article without affecting the structure of such a semi-manufactured article. Said processes can also imply the application of the first buffer layer 3 by means of irradiation, which, if necessary, can be postponed till the manufacturing phase 2 of the e/o components, which has the advantage that as a consequence in that phase the thickness of the light conducting layer can be well attuned to the dimensions of for example glass fibres to be connected to that layer.

Figure 2 diagrammatically shows in an X-Y plane a cross-sectional view of the structure of a component for e/o inducible lightwave conduction according to the invention. This structure is thought to be made on the basis of a semi-manufactured article according to Figure 1 (a), in which case corresponding layers have been numbered correspondingly. Owing to a selective irradiation from above with the aid of a mask a non-irradiated strip-shaped area 2. 1 with vertical bounding surfaces A and B and of a polymer which has remained poleable has been left open in the light conducting layer 2. Subsequently the buffer layer 3 has been provided with two strip-shaped electrodes 6 and 7 made of for example aluminium or gold, of which at least the sides 6. 1 and 7. 1 facing each other run parallel. These strip-shaped electrodes have been positioned in such a way that seen from above they flank the strip-shaped area 2. 1, either with some overlapping in the case of a lateral bounding of the area 2. 1 by the bounding surfaces A<sub>1</sub>-B<sub>1</sub> - (dash and dot line), or closely contiguous to the lateral bounding by the bounding surfaces A<sub>2</sub>-B<sub>2</sub> - (dashed line) or with a small interspace in the case of a lateral bounding by the bounding surfaces A<sub>3</sub>-B<sub>3</sub> (dotted line). A pair of bounding surfaces A<sub>i</sub>-B<sub>i</sub> - (i=1, 2 or 3) is preferably situated symmetrically with regard to the plane which is equidistant from and parallel to the sides 6. 1 and 7. 1 of the electrodes in order to make a suitable division of the inducing electric field over the strip between the pair of bounding surfaces A<sub>i</sub>-B<sub>i</sub> possible for the sake of a light waveguide to be induced in the area 2. 1. An electric voltage causing an electric field which is not uniform in the layers 2 and 3 can be applied across the electrodes 6 and 7 via the connections 8 and 9. Arrows 10 give an impression of the course of the lines of flux of said field. In a component according to Figure 2 the poling of the area 2. 1 of a poleable polymer left open preferably takes place locally with the aid of the electrodes 6 and 7 already disposed, so after the selective irradiation of the layer 2. The choice of the width of the electrodes 6 and 7 and their situation with regard to the non-irradiated area 2. 1, which is now e/o active due to poling, depends on the one hand on the thickness of the light conducting layer 2 and the possibly existing buffer layer 3, and on the

other hand on the desired dimensions of the waveguide to be induced and possibly still other wave guiding areas to be induced in the layer. An overlapping position of the electrodes 6 and 7 with regard to the e/o active area 2. 1 (so near the bounding surfaces  $A_1$ - $B_1$ ) has the advantage that the sides 6. 1 and 7.1 of the electrodes need not be sharply determined. Irregularities, if any, in the inducing field resulting from this mainly occur in the buffer layer 3, so without any influence on the refractive index profile of the waveguide to be e/o induced. When the positions of the electrodes 6 and 7 seen from above are so that they show no overlapping with regard to the e/o active area 2. 1 (i. e. near the bounding surfaces  $A_2$ - $B_2$  or  $A_3$ - $B_3$ ), they will have the advantage that the first buffer layer 3 can be dispensed with, whereas nevertheless the electrodes have no direct contact with the e/o active area 2. 1, which case is shown in Figure 2(b). An additional advantage is that the e/o area 2. 1 better comprises the area with the greatest electric flux density, due to which a better e/o inducing working is guaranteed.

A situation in which the sides 6. 1 and 7. 1 of the electrodes 6 and 7, respectively are in the same planes as the bounding surfaces  $A_2$  and  $B_2$  has the advantage that the electrodes 6 and 7 can be disposed with a similar or a complementary mask (dependent on the disposing technique used), as with which the selective irradiation of the light conducting layer 2 was carried out formerly. If the electrodes 6 and 7 are sharply defined, the selective irradiation can also be carried out after the electrodes 6 and 7 have been disposed, in which case they are used as masks.

An operating voltage with a sign appropriate to the poling and applied to the electrodes 6 and 7 by means of the connections 8 and 9 generates an E-field, which will induce within the bounding surfaces  $A_1$ - $B_1$  in the e/o active area 2. 1 a change in the refractive index over the whole length over which the strip-shaped electrodes 6 and 7 extend, thus causing an e/o induced light waveguide with a sharply determined lateral retaining (horizontally between the substrate 1 and the first buffer layer 3, or the medium between the electrodes 6 and 7, and vertically through the bounding surfaces  $A_1$ - $B_1$ ). Figures 3(a) and (b) show the qualitative course of the associated index profile. Figure 3(a) in the case of  $X = \text{constant}$  along a line through the light conducting layer 2, and Figure 3(b) in the case of  $Y = \text{constant}$  along a line at right angles to the light conducting layer 2 through the e/o area 2. 1.

The following designations are given in these figures:

$n_2$  = refractive index of the irradiated area of the light conducting layer 2;

$n_o$  = refractive index of the e/o area without an

inducing E-field;

$n_e$  = refractive index of the e/o area with an inducing E-field;

$n_1$  = refractive index of the substrate 1;

5  $n_c$  = refractive index of the first buffer layer 3 or another contiguous upper layer between the electrodes 6 and 7;

$A_i$  = Y-value of the bounding surface  $A_i$ ,

$B_i$  = Y-value of the bounding surface  $B_i$ ,

10 1-2 = X-value of the transition between the substrate 1 and the light conducting layer 2;

2-3 = X-value of the transition between the light conducting layer 2 and the first buffer layer 3 (or another contiguous upper layer between the electrodes 6 and 7).

15 The curved course of the profile between  $A_1$ - $B_1$  in Figure 3(a) and between 1-2 and 2-3 is due to the non-uniformity of the inducing E-field. The leaps in the profile indicate the sharp transitions between the e/o active area 2. 1 and e/o non-active material.

Figure 4 diagrammatically shows in the X-Y plane a cross-sectional view of the structure of a component for the e/o inducible conduction of a lightwave, as known from reference D(3) with an improved lateral definition obtained by utilizing the invention. This definition is thought to be made on the basis of a semi-manufactured article according to Figure 1(b). In this case too the corresponding layers are numbered correspondingly. Owing to a selective irradiation from above by means of a mask a non-irradiated strip-shaped area 2.1 of a poleable polymer or of a polymer which has remained poled and with vertical bounding surfaces C and D has been left open again in the light conducting layer 2. A strip-shaped electrode 11 with the edges 11. 1 and 11. 2 has been disposed on the buffer layer 3 in such a position that seen from above at least the area 2. 1 will be covered, either with some overlapping in the case of a lateral bounding of the area 2. 1 by the bounding surfaces  $C_1$ - $D_1$ , or exactly in the case of a lateral bounding by the bounding surfaces  $C_2$ - $D_2$ .

45 An electric voltage can be applied across the electrodes 4 and 11 via the connections 12 and 13, which voltage causes in the layers 2, 3 and 5 an electric field which will be uniform or well-nigh uniform in an area between the bounding surfaces  $C_1$ - $D_1$ , and which will gradually fan out more and more outside that area. Arrows 14 give an impression of the course of the lines of flux of this field.

50 Although poling of the material which forms the light conducting layer 2 can integrally take place by means of a poling voltage between the electrode 4 and a plane-shaped electrode to be temporarily disposed on the buffer layer 3 already prior to the selective irradiation, it can under certain circumstances (if for example e/o active areas with

an oppositely directed optical orientation are needed at other places in the light conducting layer) here too be preferable to poling locally after the electrode 11 has been disposed and by means of the same, so after the selective irradiation of the layer 2. The width of the electrode 11 is at least equal to the width of the e/o active area 2. 1 left open. A larger width, so seen from above in the case of an overlapping of the e/o active area 2. 1 beyond the bounding surfaces  $C_1$ - $D_1$ , has the advantage that the edges 11. 1 and 11. 2 of the electrode 11 need not be sharply defined. Irregularities, if any, resulting from this are here too in the inducing field outside the e/o active area 2. 1 and have consequently no influence on the refractive index profile of the waveguide which has to be e/o induced inside that e/o active area 2. 1. A choice of the width of the electrode 11 equal to the width of the area 2. 1, i.e. the edges 11. 1 and 11.2 are in line with the bounding surfaces  $C_2$  and  $D_2$ , respectively, has here too the advantage that by means of a similar or a complementary mask the electrode 11 can be applied to or disposed on the first buffer layer 3, as with which the selective irradiation of the light conducting layer 2 was carried out before to obtain the non-irradiated area 2. 1. In the case of a sharply defined electrode 11 the selective irradiation can here too be carried out only after that electrode 11, which then serves as a mask, has been disposed. An operating voltage with a sign corresponding to the poling voltage and applied across the electrodes 4 and 11 via the connections 12 and 13 generates an E-field, which induces within the bounding surfaces  $C_i$ - $D_i$  ( $i=1$  or  $2$ ) in the e/o active area 2. 1 a change in the refractive index over the whole length over which the strip-shaped electrode 11 extends over the e/o active area 2. 1, due to which an e/o induced light waveguide will arise with a very sharply determined lateral retaining (horizontally between the two buffer layers 3 and 5, and vertically between the bounding surfaces  $C_i$ - $D_i$ ).

Figures 5(a) and (b) show the qualitative course of a refractive index profile of an e/o induced light waveguide with a structure as represented in Figure 4. Figure 5(a) in the case of  $X=\text{constant}$  along a line through the light conducting layer 2 and Figure 5(b) in the case of  $Y=\text{constant}$  along a line at right angles to the light conducting layer 2 through the e/o area 2. 1.

The following designations are given in these figures:

$n_2$  = refractive index of the irradiated area of the light conducting layer 2;

$n_0$  = refractive index of the e/o area without an inducing E-field;

$n_{\bullet}$  = refractive index of the e/o area with an inducing E-field;

$C_i$  = Y-value of the bounding surface  $C_i$ ;

$D_i$  = Y-value of the bounding surface  $D_i$ ;

2-3 = X-value of the transition between the layer 2 and the first buffer layer;

5-2 = X-value of the transition between the second buffer layer 5 and the layer 2.

Striking in these figures is the (practically) absolute right-angled character of the index profile both in the horizontal and in the vertical direction. Consequently, such "right-angled" e/o inducible light waveguides with a very accurate lateral definition can be realized in a very simple way by utilizing the invention.

For e/o inducible light waveguides according to Figures 2 and 4 it generally applies that when the inducing E-field is removed, the refractive index in the e/o active area 2. 1 will drop to the  $n_0$  level of the non-irradiated polymer. This means that by utilizing the invention "waveguides subthreshold", as known with their advantages from reference D-(3), will as a matter of course arise in components for e/o inducible waveguides.

To conclude an e/o component adapted to an optical intermediate switch and based on a sharp e/o inducible light reflecting refractive index transition, obtained by applying the invention, will be described as an embodiment with the help of the figures 6 and 7. Figure 6 shows a top view of this embodiment in a Y-Z plane, Figures 7(a) and (b) show sectional views in X-Y planes according to the lines VII a and VII b, respectively as indicated in Figure 6. Said component again consists of a number of layers comparable to those of the component according to Figure 4, and numbered accordingly. The second buffer layer 5, however, is here thicker. During the manufacturing process a substantially X-shaped pattern as indicated by a dot and dash line in Figure 6 has been etched out in said layer 5 with a depth somewhat smaller than the thickness of the layer 5 and with for example a right-angled cross section. The layer 2 of the glassy poleable material with an e/o activity which is destructible under an ionizing radiation has been applied to said layer 5. At the same time said material entirely fills up the etched-out X-shaped pattern. Said layer 2 has been integrally irradiated with the exception of the e/o active area 2. 1, which has a substantially right-angled section in front view as well as in top view (see the dashed line in Figure 6 as well as in Figure 7(b)), and which divides the X-shaped pattern in two.

The material of the first and the second buffer layers 3 and 5 has a refractive index which is lower than the one of the irradiated material of the light conducting layer 2. In this way permanent light waveguides 21, 22, 23 and 24 of the "inverted ridge"-type have been formed in the X-shaped pattern, which light waveguides are connected to

the area 2. 1 at an angle  $\alpha$ , so that the light waveguides 23 and 24 are in line with the light waveguides 21 and 22, respectively. On the first buffer layer 3 the electrode 11 seen from above covers the area 2. 1, which has been made e/o active by for example a local poling by means of a poling voltage applied across the electrodes 5 and 11 via the connections 12 and 13. By applying across the electrodes an operating voltage of a sufficient height and with a negative sign with regard to the poling voltage, a refractive index decrease is induced in the area 2. 1 in such a way that that refractive index will become about equal to that of the second buffer layer 5. The angle  $\alpha$  has been chosen in such a way that the induced refractive index reduction will effect a totally reflecting refractive index transition for each light signal incident via one of the permanent light waveguides 21-24. If there is no inducing E-field, an incident light signal will find a thin plane-parallel layer with a small positive refractive index leap, due to which the signal will experience a small shift with regard to the direction of incidence. Although at the same time some reflection will occur, the signal will be able to propagate practically unweakened in that permanent light guide which is in line with the light guide along which the light signal has entered.

Figure 8 shows the qualitative course of an associated index profile according to the sectional line VII b.

The following designations are given in this figure:

- $n_2$  = refractive index of the irradiated area of the layer 2;
- $n_o$  = refractive index of the e/o area 2. 1 without an E-field;
- $n_{\bullet}$  = refractive index of the e/o area 2.1 with an inducing E-field;
- $n_5$  = refractive index of the second buffer layer 5;
- 5-24 = Y-value of the transition from the layer 5 to the guide 24;
- 24-2. 1 = Y-value of the transition from the guide 24 to the area 2. 1;
- 2. 1-23 = Y-value of the transition from the area 2. 1 to the guide 23;
- 23-5 = Y-value of the transition from the guide 23 to the layer 5.

Although only three embodiments have been described in detail in what precedes, the application of the invention is not restricted to those embodiments. Wherever in integrated optical components preferably e/o inducible refractive index transitions are desired, the invention can be utilized with great advantage. So this also applies to periodical structures, such as gratings as used inter alia in electro-optical grating reflectors or deflectors. It is known to excite suchlike gratings in thin layers of e/o material by means of periodical elec-

trode structures. The quality of such gratings is strongly dependent on the quality (sharpness) of the electrodes. When in the case of one-sidedly disposed electrodes so-called "interleaved" electrodes are used, there is moreover the risk of short-circuiting. By utilizing the invention the grating structure can be established directly in the light conducting layer by means of a selective irradiation, in which case the whole grating structure can preferably be sandwiched between two plane-shaped electrodes, as a result of which a photolithographic step for applying the periodical electrode structure can be omitted. Moreover an absolute uniformity of the inducing electric field over the whole grating structure is guaranteed, due to which every bar of that grating structure can be induced in an extremely sharp way.

## Claims

### 1. Electro-optical component comprising:

- a mainly plane light conducting layer comprising a certain e/o active area, and
  - at least two at least partly co-operating electrodes disposed against said layer in preselected patterns, between which electrodes an electric field with a working extending into the e/o active area can be generated by applying a difference in voltage between said electrodes,
- characterized in that the light conducting layer consists of material with an under ionizing radiation destructible e/o activity, in which the e/o active area is left open beforehand by means of selective irradiation, and in that the electrodes have been positioned with regard to the area left open in such a way that a difference in voltage applied across the electrodes induces such a field distribution that at least in a border area on either side of the place where the area left open borders on irradiated material the electric field will show a high degree of intensity and/or uniformity.

2. Electro-optical component in accordance with claim 1, characterized in that the electrodes are kept separated from the e/o active area by buffer material which belongs to the irradiated part of the plane light conducting layer.

3. Electro-optical component in accordance with claim 1 or 2, characterized in that the electrodes are situated on one side, called upper side, of the light conducting layer, and in that the e/o active area left open includes an e/o inducible light waveguide pattern, the e/o active area on the upper side seen in a perpendicular projection on the layer being flanked by a corresponding pattern of co-operating strip-shaped electrodes.

4. Electro-optical component in accordance with claim 1 or 2, characterized in that the electrodes are situated on both sides on the upper side and on the under side of the light conducting layer, and in that the e/o active area left open includes an e/o inducible light waveguide pattern, the e/o active area on the upper side seen in a perpendicular projection on the layer being covered by a corresponding pattern of strip-shaped electrodes.

5. Electro-optical component in accordance with one of the preceding claims 1-4, characterized in that the e/o active area left open in the layer has, lateral with regard to that layer, substantially vertical bounding surfaces with the irradiated area, and in that seen from the upper side in a perpendicular projection on the layer the contours of the electrodes situated on the upper side of the layer and of the e/o active area left open at least partly coincide.

6. Electro-optical component in accordance with claim 1 or 2, characterized in that the e/o active area left open includes an e/o inducible light waveguide pattern, and in that the electrodes extend on both sides on the upper side and on the under side of the light conducting layer plane-shaped over the whole layer.

7. Electro-optical component in accordance with claim 1 or 2, characterized in that the e/o active area left open includes an e/o inducible grating pattern and in that the electrodes extend on both sides on the upper side and on the under side of the light conducting layer plane-shaped at least over the whole grating pattern.

8. Electro-optical component in accordance with claim 1 or 2, characterized in that the light conducting layer includes at least one permanent light waveguide connected to the e/o active area left open in said border area.

9. Optical switch comprising an e/o component in accordance with claim 8, characterized in that the light conducting layer includes at least three permanent light waveguides, which are connected to the e/o active area left open in said border area, and in that the connection of each of the light waveguides to this area takes place at such an angle that for a light signal incident through one of the permanent light waveguides a totally reflecting refractive index transition can be induced, and that when there is a refractive index transition inducing field or not, one of the other permanent light waveguides will receive and further conduct the light signal.

10. Optical switch in accordance with claim 9, characterized in that the light conducting layer includes 4 permanent light waveguides, which are connected to an e/o active area left open with, seen from above, a narrow rectangular section.

11. Method for making an e/o component according to one of the preceding claims 1-10 for introducing an e/o active area into a plane light conducting thin layer characterized in that this introducing takes place by leaving open the e/o active area in the plane light conducting layer by means of selective ionizing irradiation.

12. Method for making an e/o component in accordance with claim 11, characterized in that the ionizing irradiation is carried out by making use of U.V.light.

13. Method for making an e/o component in accordance with claim 5 by applying photolithographic techniques, characterized in that the e/o active area left open in the plane light conducting layer is obtained by selective ionizing irradiation by means of a mask which is also used for the electrode pattern to be disposed.

14. Method for making an e/o component in accordance with claim 13, characterized in that the selective ionizing irradiation takes place by means of a mask formed by the electrode pattern itself.

15. Semi-manufactured article for making an e/o component in accordance with claims 1-8 comprising a mainly plane light conducting layer supported on one side, the under side, by a substrate, and provided on the opposite side, the upper side, with a light insulating first buffer layer, characterized in that the light conducting layer consists of a material with an under ionizing radiation destructible e/o activity, which layer has a first sublayer of said material non-irradiated, and a second sublayer of said material irradiated and forming the first buffer layer.

16. Semi-manufactured article in accordance with claim 15, which further comprises a second buffer layer, which keeps an electrode layer applied to the substrate separated from the light conducting layer, characterized in that the second buffer layer consists of said irradiated material.

FIG.1

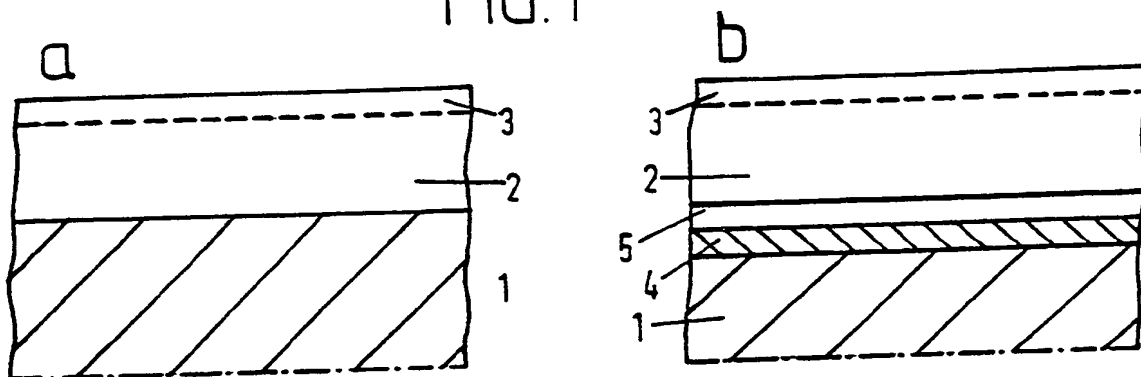


FIG.2

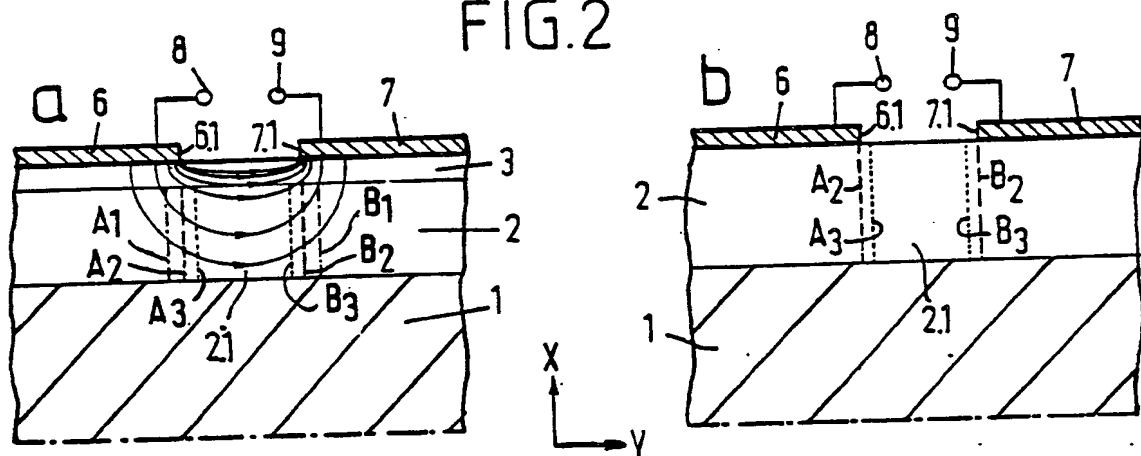


FIG.3

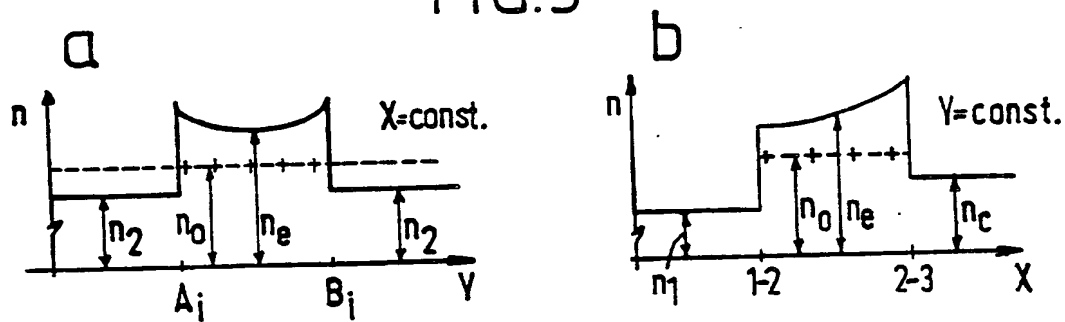
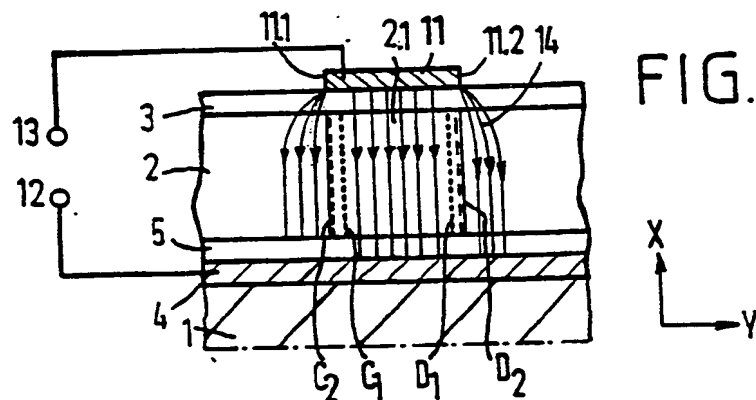


FIG.4







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## EUROPEAN SEARCH REPORT

Application Number

EP 89 20 1370

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
D,A	EP-A-0 241 967 (STAATSBEDRIJF DER POSTERIJEN, TELEGRAFIE EN TELEFONIE) * Abstract *	1	G 02 F 1/00 G 02 F 1/01
D,A	US-A-3 801 185 (V. RAMASWAMY et al.) * Abstract *	1	
D,A	US-A-3 695 745 (M. FURUKAWA) * Abstract *	1	
A	EP-A-0 021 967 (THOMSON-CSF) * Claim 1 *	1	
A	ELECTRONICS AND COMMUNICATIONS IN JAPAN, vol. 65-C, no. 11, 1982, pages 101-107, Scripta Publishing Co.; I. KATO et al.: "Polymer thin film optical waveguide"		
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The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (Int. Cl.4)
			G 02 F
Place of search		Date of completion of the search	Examiner
THE HAGUE		11-09-1989	GALANTI M.
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